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Microstructures, Strength Characteristics and Wear Behavior of the Fe-based P/M Composites after Sintering or Infiltration with Cu–Sn Alloy

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Some properties of the Fe-based P/M composites sintered and reinforced by infiltration with Cu–Sn alloy were described. It is shown that the hardness of the sintered material is 2.5 times lower, tensile strength is 1.7 times lower and the wear resistance is 2.5–3.3 times lower in comparison with those of the infiltrated material. The presence of pores on the friction surface of the sintered material affects the features of the wear process. Due to the specific morphology of copper in the infiltrated material, the phenomenon of selective mass transfer is observed and worn surfaces have a spongy-capillary texture.

1. Introduction

Currently, the use of powder metallurgy (P/M) materials has increased because of their low cost and absence of or a minimum need for metalworking processes. The main advantage of the P/M technology is the possibility of composing new materials with unique properties, which cannot be obtained by standard melting-casting processes.

Nowadays different compositions of Fe-based P/M materials are used in industry, in particular[1]: P/M iron and carbon steels, P/M copper steels, P/M nickel steels, P/M low alloy steels, P/M sinter-hardened steels and so on. P/M copper steels have good operational properties, and parts made from these materials, such as slide bearings, operate successfully in different types of machines.

Composites based on the iron–copper system are the powder materials most commonly used for parts of friction units. They consist of components that are produced in large quantities at a relatively low cost[2]. The iron provides the strength and hardness, and the copper phase ensures the ductility and thermal conductivity of composites. The properties of powder materials are determined by the phase composition and the structure morphology. These characteristics of the material are formed during sintering and depend on the technological factors (the purity of the starting powders, temperature, time, atmosphere of sintering) as well as the chemical composition, diffusion processes, and phase transformations in the starting materials.

Composite powder materials based on the iron–copper system obtained by pressing and sintering have good tribological properties, but their high residual porosity (15–20 wt%), low strength and thermal conductivity make them difficult to be used in heavy-duty friction units[2]. Under such conditions, the materials should not only have good tribological properties, but also, according to operating conditions, should have a sufficiently high mechanical strength, high thermal conductivity, resistance to oxidation at elevated temperatures, the stability of mechanical properties at operating temperatures, etc. Consequently, materials with less porosity should be used.

From this viewpoint, the prospective process for producing high density composites based on iron–copper system is the infiltration of a Fe-based skeleton, obtained by powder metallurgy, with copper or copper alloys[3]. The porosity of the skeleton after infiltration, which is reduced to 5%–7%, increases the strength, hardness and corrosion resistance in a humid atmosphere, alkalis and solutions of salts[4].

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Actually, additives to the metal matrix can be introduced directly while sintering P/M metal matrix composites (MMCs)[1,5,6], or be impregnated with a liquid metal (infiltration). The motive force of an infiltration process may be either the capillary force of the dispersed phase (called spontaneous infiltration) or an external gaseous, mechanical, electromagnetic, centrifugal, or ultrasonic pressure applied to the liquid matrix phase (called forced infiltration)[1]. So, infiltration of a liquid metal into a preform is carried out either by pressureless or pressure-assisted methods.

Different metal compositions may be infiltrated, such as tungsten–cobalt and tungsten–nickel mixtures[7], alumina–steel composites[8], low alloy steels[9]. Copper[5,7] and copper–zirconium alloys[10,11] are the most widely used infiltrating materials due to their good wetting properties. According to Reference [9], the molten copper is drawn into the interconnected pores of the matrix by capillary action.

Several advantages of infiltration of Fe-based structural parts with copper alloys are known[12]:

- mechanical properties are increased (higher tensile strength and hardness, greater impact energy and fatigue strength);
- infiltration ensures higher density and tends to even out density variations;
- infiltration can be used as a method to seal surface porosity so that secondary operations such as pickling and plating can be performed without damaging the interior of the part. It is also a method of sealing a part used for applications in which no porosity is desired;
- by infiltrating only selected areas of a part it is possible to obtain a controlled variation of properties in the part (density, strength, and hardness);
- different sections of the final part, pressed separately, can be assembled by sintering the individual pieces together and by bonding the pieces into one part through common infiltration.

The main advantages of pressure assisted infiltration are: faster processing and near-net shape processing[13]. On the other hand, pressureless melt infiltration besides these advantages is more attractive due to its cost effectiveness[6].

In this paper, the effect of liquid infiltration of Fe-based MMCs on their structures and some mechanical and tribological properties was reported.

2. Experimental

2.1. Base powders and P/M materials

Ready-made powders of iron, copper and graphite were used. The particulates of the atomized iron powder were of the size less than 200 μm. The particulates of electrolytic copper powders were less than 50 μm in size. Graphite with particulates sized less than 40 μm was used as carbon. MoS_2 powder of 0.5 wt% was used as the additive in Fe-based skeleton, whose particulates were of the size of 50–80 μm.

2.2. Preparation of composite samples

Powder Fe-based MMCs that involve a considerable quantity of copper were investigated. Materials of that type are used for heavily loaded slide bearings[1]. To improve operational properties of composites, tin may be added to the infiltrating copper, because tin-containing alloys have a good embeddability, conformability and resistance to seizure[14–16].

To improve tribological properties of tested composites, MoS_2 particulates were also added in the skeleton. They have a layered structure, wherein molybdenum atoms are sandwiched between layers of sulfur atoms, and due to this they act as a common dry lubricant[17]. It is known that the presence of such additives increases wear resistance and decreases friction coefficients[18–20].

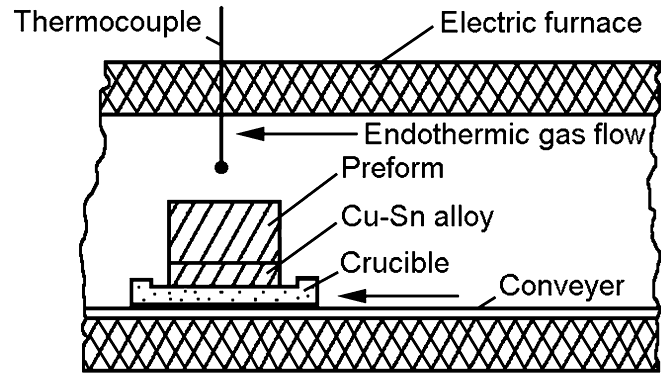

Fig. 1. Scheme for sample infiltration.

Two composite materials of the same composition, namely, FeGr1Cu19Sn0.9(MoS_2)0.5, obtained by different technologies were compared. The composites were obtained by sintering FeGr1Cu19Sn0.9(MoS_2)0.5 material or by infiltrating CuSn5 alloy into a skeleton of FeGr1Cu2(MoS_2)0.5 composition. For comparison, the sintered FeGr1(MoS_2)0.5 material was also considered. The mixture of components was prepared in a mixer of "drunken barrel" type for 0.5 h. Then the samples of 80%–83% density were pressed by using a hydraulic press. The samples were sintered or infiltrated in an electric belt furnace in the atmosphere of an endothermic gas at 1100 °C for 1 h.

The infiltrated samples were pressed by using a hydraulic press to obtain a density of 65%–70%.

The contact infiltration process was used to prepare the composite samples. To ensure right heating of both Fe-based and Cu–Sn materials, unsintered preforms of the base material were placed above the pellets of the infiltrant in crucibles on the conveyer of the furnace. In this case, preforms of the base material warm up first, and after melting Cu–Sn preforms the liquid phase penetrates into the pores (Fig. 1). In addition, gas displacement from the pores is aided by placing the infiltrant beneath the skeleton.

In order to know the quantitative content of composition elements, carbon was determined by conductance-measuring method using AN7529M quick/spot tester, whereas tin and copper were determined by using ED2000 X-ray fluorescence analyzer. Measurements were repeated 3 times. So, the quantitative content of elements included in tested compositions is an averaged value, the variance was 5%–7%. It should be noted that tin interacts with copper when melting to form a solid solution; therefore the vaporization of tin when sintering and infiltrating is very small and does not affect the quantitative content.

2.3. Microstructures and SEM examinations

The microstructure of cross sections of the specimens was examined using an MEF-3 optical microscope. Cross sections were etched in a 4% solution of a picric acid in an ethyl alcohol. The elemental compositions were analyzed using a Phenom ProX desktop scanning electron microscope. It is a low vacuum ultimate all-in-one imaging and X-ray analysis system with very short loading of a sample. It allows to view three-dimensional images of microscopic structures as well as identifying the different chemical elements in a sample.